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Charge Conservation and Flow

- STAR's parity observable

- Relation to Balance Functions

- Blast wave results
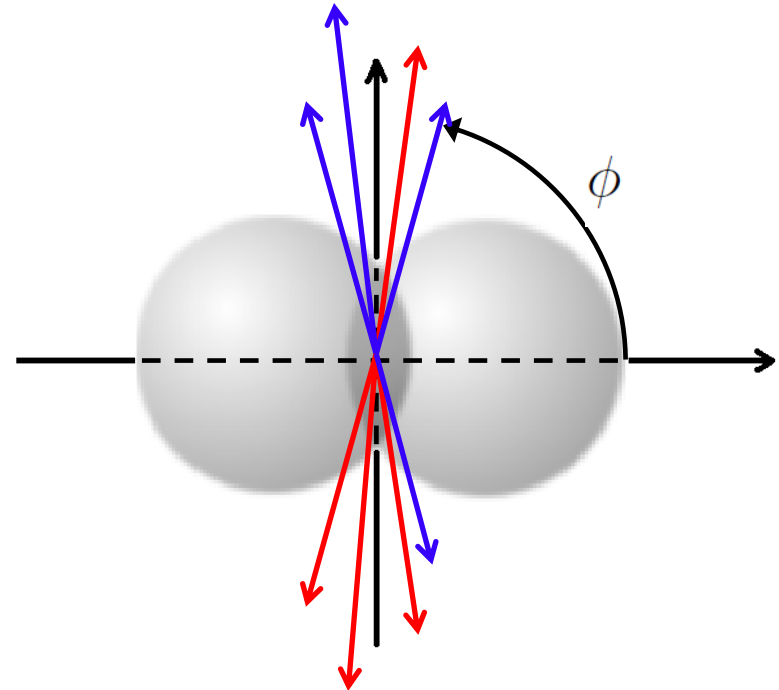
STAR's parity observable

- anomalous coupling of the initial B field to the QCD topological charge

- coherent electric field out-of-plane

- charge separation in out-of-plane direction

$$\frac{dM_\alpha}{d\phi} \propto 1 \quad + 2\, v_2 \cos(2\phi) + ...$$

$$+\; \boxed{v_{1,\alpha}} \sin(\phi) + ... \quad \text{fluctuates}$$

(Kharzeev, Nucl. Phys. A 830, 534C (2009))
(STAR, PRL 103, 251601 (2009))

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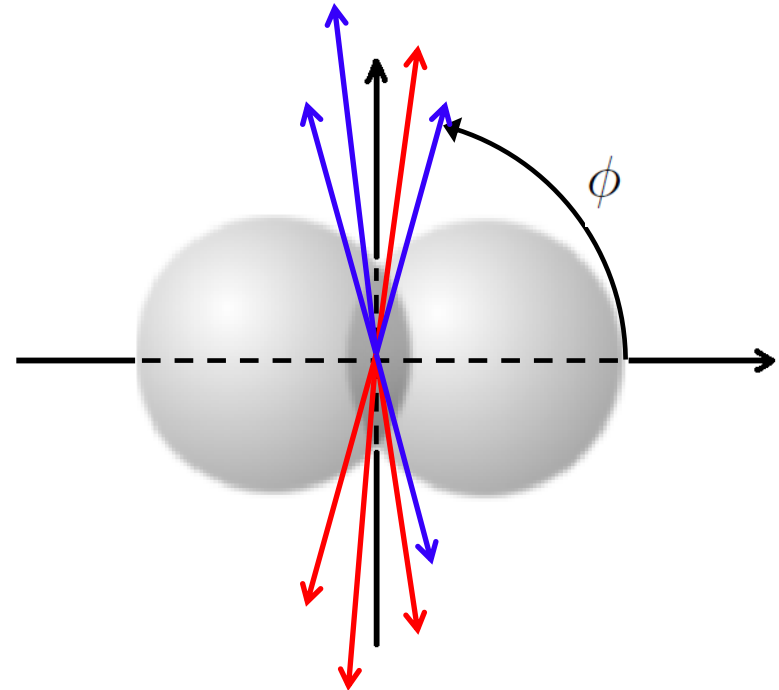
STAR's parity observable

- correlations between charged particles

$$\gamma_{\alpha,\beta} = \frac{\sum_{i\in\alpha,j\in\beta} \cos(\phi_i + \phi_j)}{M_\alpha M_\beta}$$

$$= \frac{\sum_{i\in\alpha,j\in\beta} \cos\phi_i \cos\phi_j - \sin\phi_i \sin\phi_j}{M_\alpha M_\beta}$$

- compare out-of-plane to in-plane

- compare same-sign to opposite-sign

$$\gamma_P \equiv \frac{1}{2}\left[2\gamma_{+-} - \gamma_{++} - \gamma_{--}\right]$$

Effects of Charge Conservation

- Charge Balance Function:

$$B(\phi, \Delta\phi) = \frac{N_{+-}(\phi, \Delta\phi) - N_{++}(\phi, \Delta\phi)}{dM/d\phi} + \frac{N_{-+}(\phi, \Delta\phi) - N_{--}(\phi, \Delta\phi)}{dM/d\phi}$$
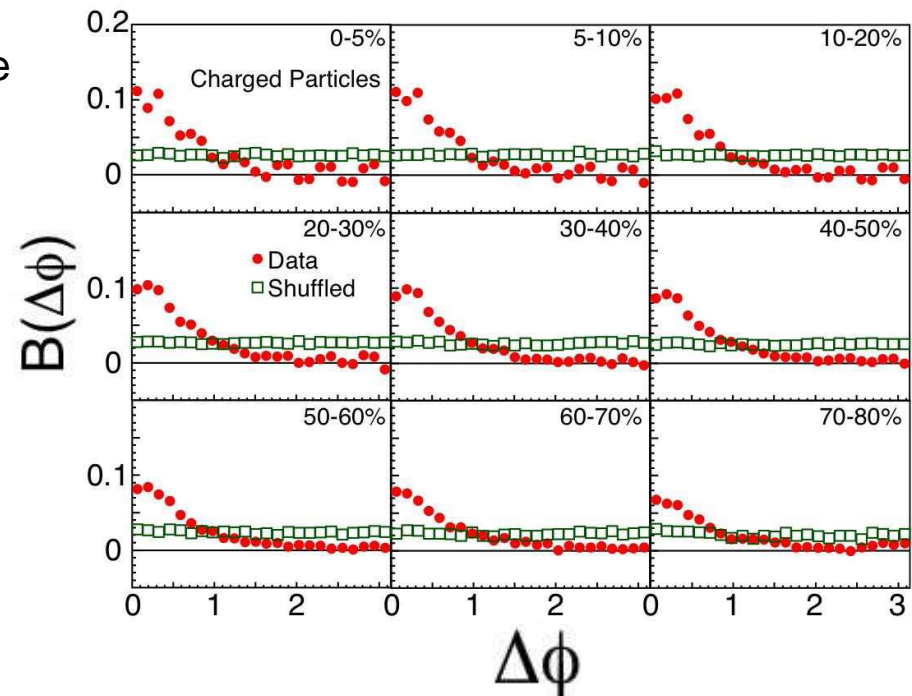
- balancing charge likely to be emitted in close

proximity

(STAR, arXiv:1005.2307v1 [nucl-ex] (2010))

- consistent with thermal models for

central collisions

(Cheng, Petricioni, Pratt et al.

PRC 69 054906 (2004))

Charge conservation + Flow contributions

$$\gamma_P = \frac{2}{M^2} \int \, d\phi \, d\Delta\phi \, \frac{dM}{d\phi} \, B(\phi, \Delta\phi) \, [\cos 2\phi \cos \Delta\phi - \sin 2\phi \sin \Delta\phi]$$

▪ essentially three contributions

$$\gamma_P = \frac{2}{M} [v_2 \langle c_b \rangle + v_{2c} - v_{2s}]$$

$$\langle c_b \rangle \equiv \frac{1}{M} \int \, d\phi \, d\Delta\phi \, \frac{dM}{d\phi} \, B(\phi, \Delta\phi) \, \cos \Delta\phi$$

$$v_{2c} \equiv \frac{1}{M} \int \, d\phi \, d\Delta\phi \, \frac{dM}{d\phi} \, \left[B(\phi, \Delta\phi) \cos 2\phi \cos \Delta\phi - \frac{v_2 \langle c_b \rangle}{2\pi} \right]$$

$$v_{2s} \equiv \frac{1}{M} \int \, d\phi \, d\Delta\phi \, \frac{dM}{d\phi} \, B(\phi, \Delta\phi) \sin 2\phi \sin \Delta\phi$$
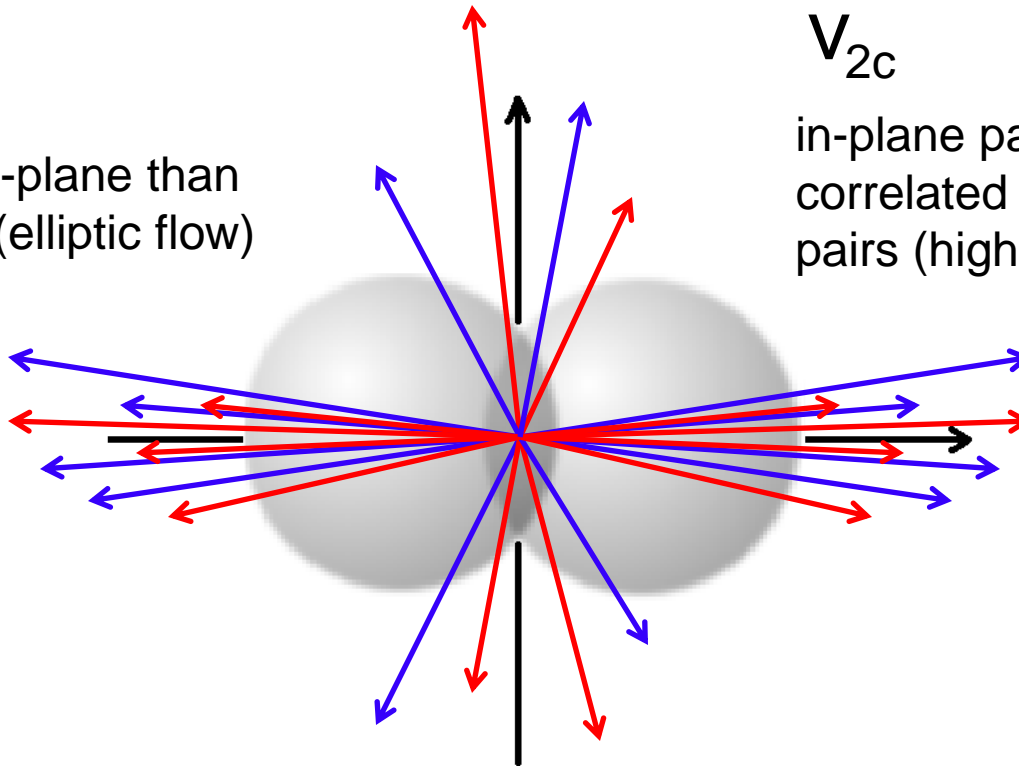
(Pratt, arXiv:1002.1758v1 [nucl-th])

(Schlichting, Pratt arXiv:1005.5341v2 [nucl-th] (2010))

$V_2 <C_b>$

more pairs in-plane than
out-of-plane (elliptic flow)

V_{2c}

in-plane pairs more tightly
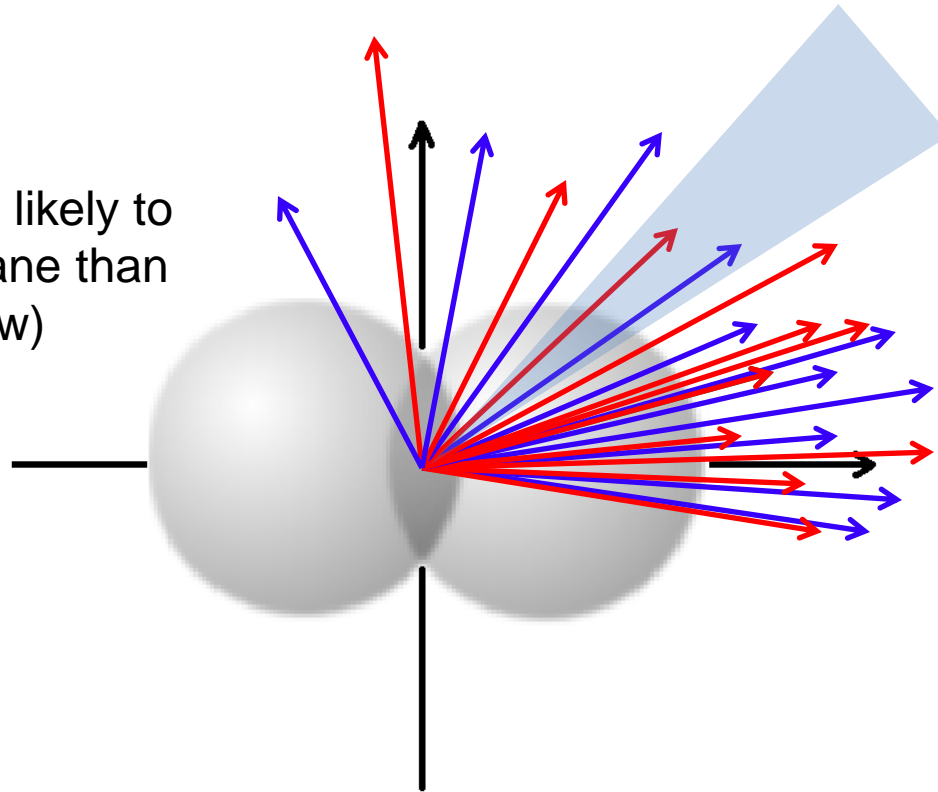correlated than out-of-plane
pairs (higher coll. velocity)

$$v_2 \langle c_b \rangle \equiv \frac{v_2}{M} \int d\phi \, d\Delta\phi \, \frac{dM}{d\phi} \, B(\phi, \Delta\phi) \, \cos \Delta\phi$$

$$v_{2c} \equiv \frac{1}{M} \int d\phi \, d\Delta\phi \, \frac{dM}{d\phi} \left[B(\phi, \Delta\phi) \cos 2\phi \cos \Delta\phi - \frac{v_2 \langle c_b \rangle}{2\pi} \right]$$

V$_{2s}$

balancing charge more likely to
be found towards in-plane than
out-of-plane (elliptic flow)

$$v_{2s} \equiv \frac{1}{M} \int d\phi \, d\Delta\phi \, \frac{dM}{d\phi} \, B(\phi, \Delta\phi) \sin 2\phi \sin \Delta\phi$$
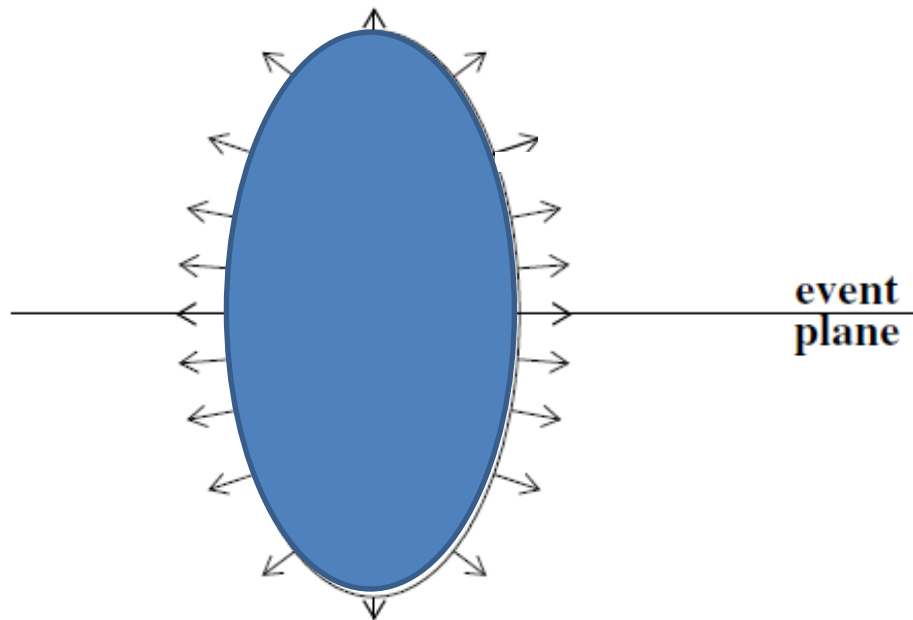
The Model - Ingredients

- Collective Flow (parameters from STAR)

- Charge Conservation (local)

- Detector Acceptance & Efficiency

Collective Flow

▪ Blast wave parametrization to fit elliptic flow and particle spectra

(STAR, PRC 72, 14904 (2005))

event plane

Charge Conservation

▪ Canonical ensembles with zero net charge (electric, strangeness and baryon number)

▪ For a given ensemble all particles are emitted from the same collective velocity, with thermal momenta in the rest frame (strongest possible correlation)

(Cheng, Petricioni, Pratt et al., PRC 69 054906 (2004))

(Schlichting, Pratt arXiv:1005.5341v2 [nucl-th] (2010))
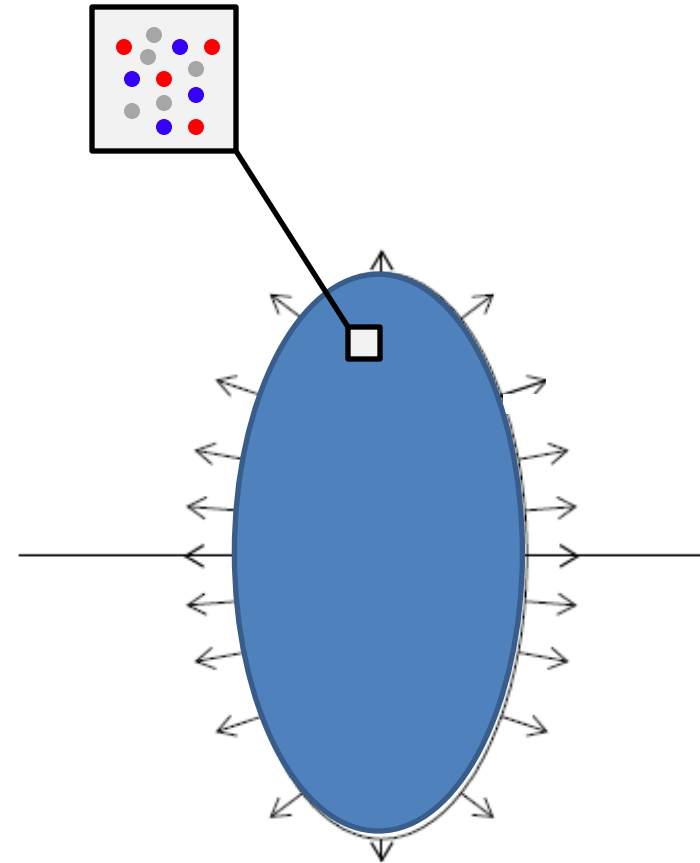
- stronger correlations in-plane than out-of-plane

- balancing charge more likely to be found in in-plane than in out-of-plane direction for intermediate angles
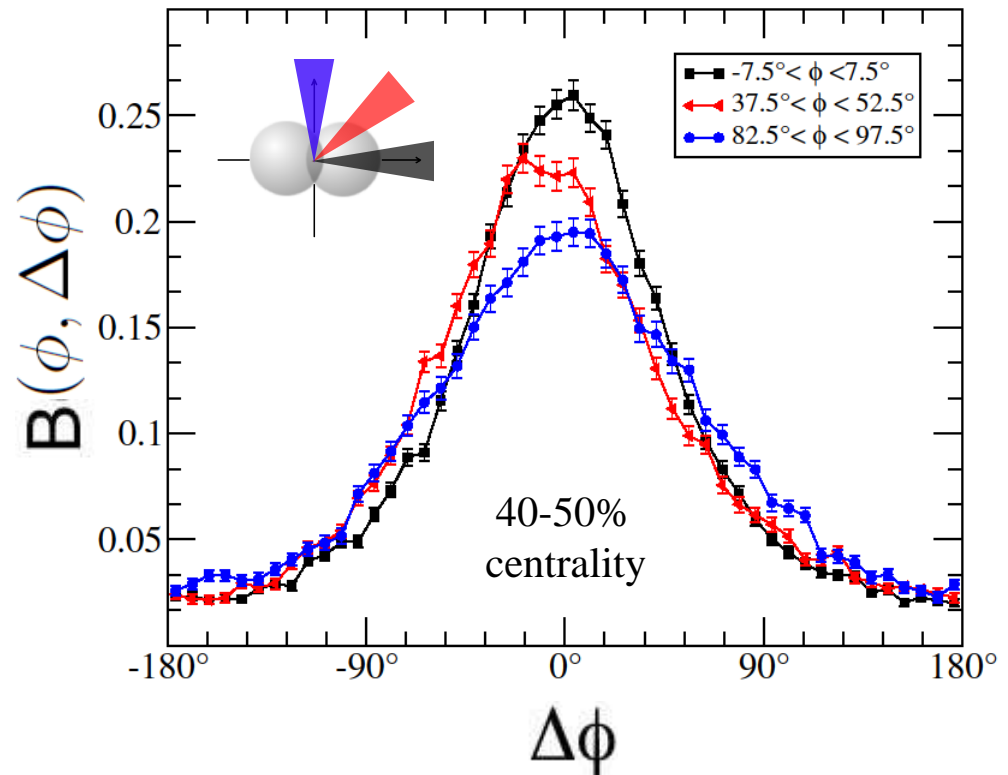
(Schlichting, Pratt arXiv:1005.5341v2 [nucl-th] (2010))

Normalization Corrections

$$\gamma_P = \frac{2}{M}[v_2\langle c_b\rangle + v_{2c} - v_{2s}]$$

$$v_2\langle c_b\rangle \equiv \frac{v_2}{M}\int d\phi\, d\Delta\phi\, \frac{dM}{d\phi} B(\phi, \Delta\phi)\cos\Delta\phi$$

$$v_{2c} \equiv \frac{1}{M}\int d\phi\, d\Delta\phi\, \frac{dM}{d\phi}\left[B(\phi, \Delta\phi)\cos 2\phi\cos\Delta\phi - \frac{v_2\langle c_b\rangle}{2\pi}\right]$$

$$v_{2s} \equiv \frac{1}{M}\int d\phi\, d\Delta\phi\, \frac{dM}{d\phi} B(\phi, \Delta\phi)\sin 2\phi\sin\Delta\phi$$

- use experimental multiplicities (not corrected for efficiency and acceptance)

(generously provided by STAR)

- rescale balance function to reproduce experimental normalizations

(accounts for detector efficiency and acceptance)

(STAR, arXiv:1005.2307v1 [nucl-ex] (2010))

- correlations consistent with model for more central collisions
- overpredicted for more peripheral collisions

- BUT model assumes emission from same collective velocity and therefore strongest possible correlations
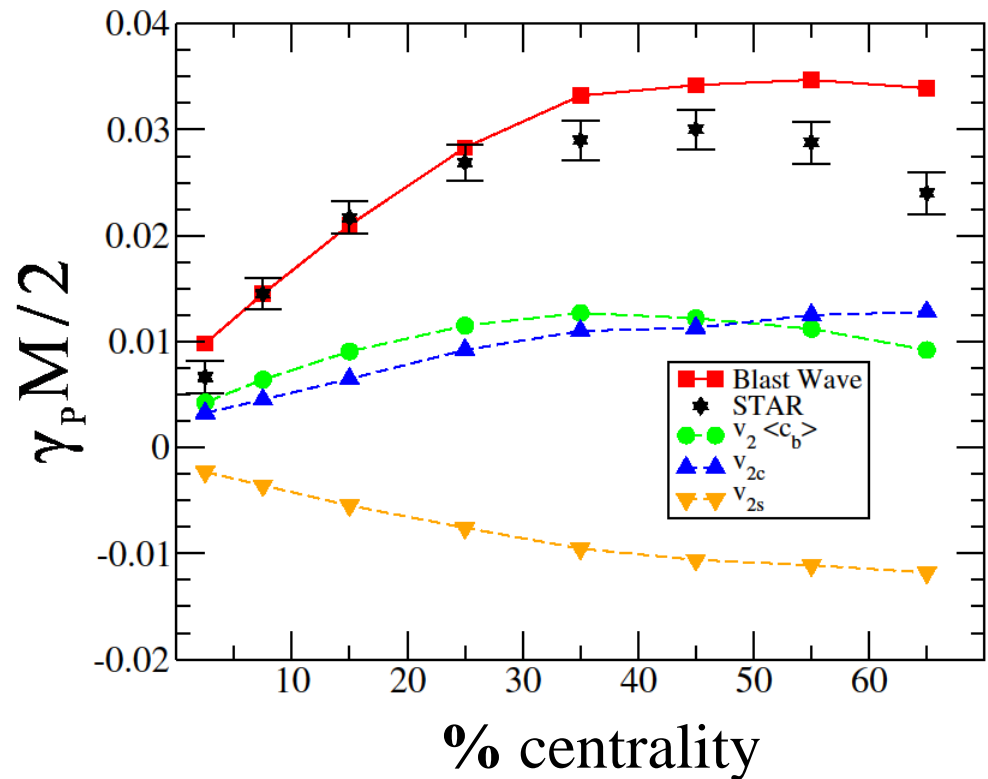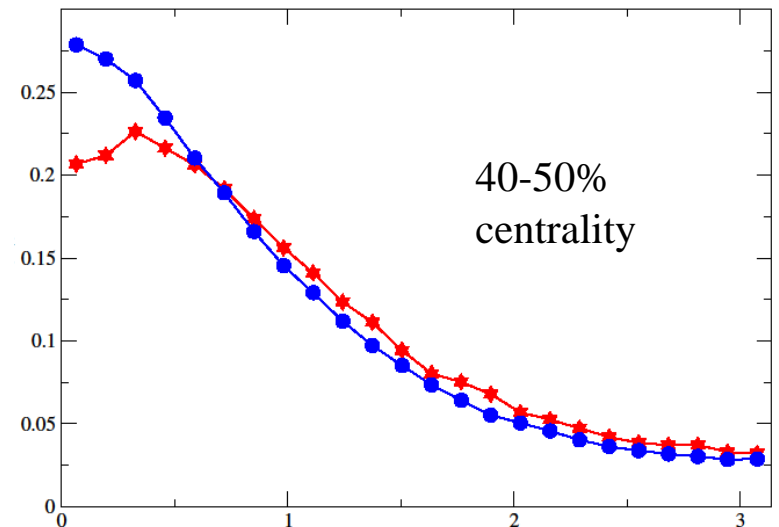

(Schlichting, Pratt arXiv:1005.5341v2 [nucl-th] (2010))
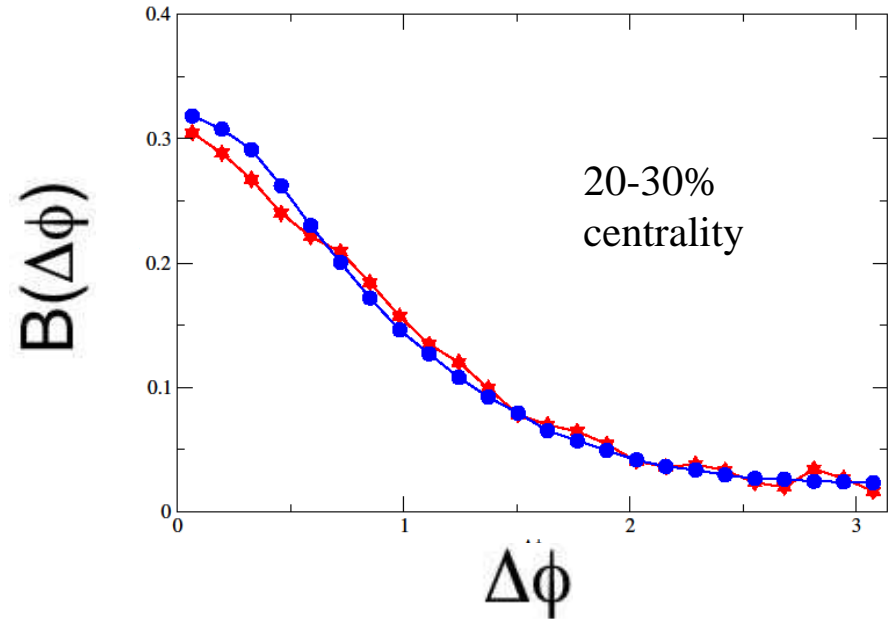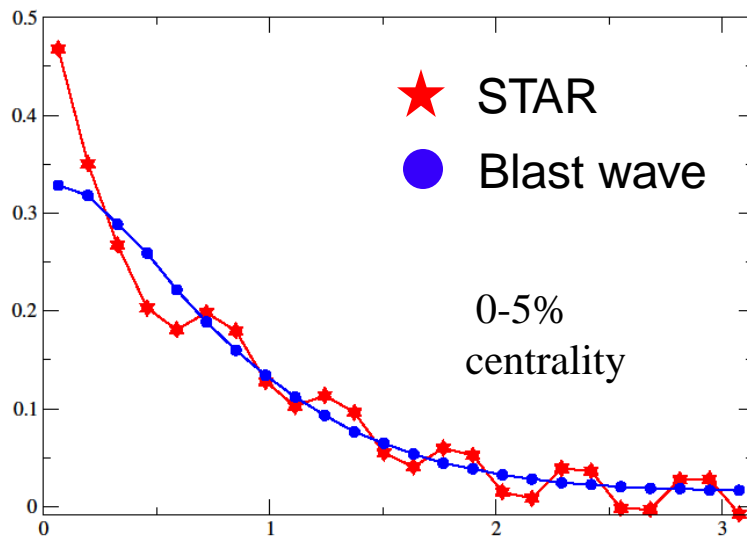
More differentially:

- experimental balance functions for more central collisions consistent with thermal emission from the same angle
- not so for more peripheral collisions

Conclusion

- difference of same-sign and opp.-sign correlations readily explained by charge conservation combined with flow

- strong same-sign correlations have yet to be explained (momentum conservation proposed as one possible source) (Pratt, arXiv:1002.1758v1 [nucl-th])

- future models should describe both parts independently and reproduce the more detailed differential observables as well